

*THE EFFECT OF FOREPERIOD DURATION ON  
REACTION TIME AND ITS RELATION TO  
INTERVAL SCHEDULES OF REINFORCEMENT*

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Two groups of pigeons were exposed to a simple reaction-time procedure in which mean foreperiod duration was 5, 10, or 20 seconds. For one group, the foreperiods had an arithmetic, or rectangular, distribution; for the second group, they had a constant-probability, or Bernoulli, distribution. Under both distributions, mean response latency was an increasing, negatively accelerated function of mean foreperiod duration. On a given trial, response latency was a function of its associated foreperiod duration: latency was a decreasing function of foreperiod duration in the arithmetic distribution, and an increasing function of foreperiod duration in the constant-probability distribution. Examination of the distribution of latencies revealed a harmonic structure reminiscent of distributions of interresponse times under variable-interval schedules of reinforcement. Taken together, the results confirm and extend previous findings with human subjects, and also suggest numerous similarities to behavior maintained by variable-interval schedules.

*Key words:* foreperiod duration, reaction time, response latency, variable-interval schedules, arithmetic and constant probability, key peck, pigeons

Most early studies of simple reaction time were concerned with the behavioral effect of the physical stimulus. In these studies, the interval between a warning signal and the stimulus to which the subject was to respond, or *foreperiod*, was assigned a variable duration as a method for reducing the frequency of "anticipatory" responses: that is, responses made before stimulus presentation or so soon afterward as to be a dubious effect of the stimulus itself. In more recent years, however, the foreperiod has come to be viewed as a determinant of reaction time that is quite worthy of study in its own right.

When foreperiod duration is fixed within blocks of trials, well-controlled studies, such as that of Karlin (1959), have usually found mean reaction time to be an increasing, negatively accelerated, function of foreperiod length. When, within blocks of trials, the foreperiod duration is variable, a very similar relation is obtained between mean reaction time and mean foreperiod duration (Klemmer, 1956; Näätänen, 1971; Nickerson and Burn-

ham, 1969). Although reaction time is generally shorter for fixed foreperiods than it is for variable foreperiods of an equivalent mean length, the form of both functions is very similar.

Inspection of reaction time on each trial reveals that it covaries with the length of its associated foreperiod. The foreperiod distribution to which such a trial-by-trial analysis has most often been applied is one in which each of a set of foreperiod durations, differing from one another by an additive constant, is presented with an equal likelihood on each trial. Such a rectangular distribution of foreperiods corresponds to the distribution of interreinforcement intervals in an arithmetic variable-interval (VI) schedule of reinforcement (Catania and Reynolds, 1968), though generally without the inclusion of a 0-sec interval. With this distribution, human reaction time (Drazin, 1961; Karlin, 1959; Klemmer, 1956) and that of cats (Macar, Vitton, and Requin, 1973) has been shown to decrease with longer associated foreperiods. In other words, this local relationship is the opposite of that which describes the effect of mean foreperiod duration on mean reaction time, over trials. In an arithmetic distribution, the chance that a stimulus will be presented increases as the interval grows longer (*cf.* Flesh-

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ler and Hoffman, 1962, p. 529). Näätänen (1971), and others, have argued that it is this growing conditional probability of stimulus presentation that accounts for the shortening of reaction time at longer foreperiod durations.

Consider, however, the situation where at every instant in time ( $T$ ) there is a constant probability ( $p$ ) that a stimulus will be presented. When the values of  $T$  and  $p$  are made small, the distribution of foreperiod durations approaches an exponential, there being many more short foreperiods than long ones. Unlike the arithmetic distribution, the likelihood of stimulus presentation is independent of how much time has elapsed in the foreperiod. This method of generating foreperiods shares much in common with the programming of inter-reinforcement intervals in a random-interval schedule of reinforcement (Millenson, 1963) and with constant-probability VI schedules (Catania and Reynolds, 1968; Fleshler and Hoffman, 1962).

If the conditional probability of stimulus presentation is an important determinant of reaction time, then we might expect that there would not be an inverse relation between foreperiod duration and reaction time when the foreperiods are drawn from a constant-probability distribution. For very short foreperiods, this expectation has not been confirmed. Nickerson (1967) found that the reaction time to the second of two signals varied inversely with the duration of the interval between signals, for intervals up to approximately 250 msec. For longer durations, however, it does appear that constant-probability distributions produce a quite different foreperiod-reaction time relationship from that obtained with arithmetic foreperiod distributions. Although data collected by Näätänen (1971) are generally too variable to be readily characterized, those of Granjon, Requin, Durop, and Reynard (1973) clearly indicate that with a constant-probability distribution, reaction times increase somewhat with longer foreperiod durations. In other words, the effects are the opposite of those obtained with arithmetic foreperiod distributions.

The bulk of the studies cited above used human subjects; the present experiment used pigeons. Reaction time was studied under three different values of mean foreperiod duration, with both arithmetic and constant-prob-

ability distributions. The data confirm and extend previous findings with humans, and also suggest intriguing similarities to the pigeon's behavior under arithmetic and constant-probability schedules of VI reinforcement.

## METHOD

### *Subjects*

Eight locally obtained 1- to 2-yr-old male homing pigeons were maintained at approximately 80% of their free-feeding body weights. All had some prior training under a variety of reinforcement schedules.

### *Apparatus*

Four identical Lehigh Valley Electronics three-key pigeon chambers were used. Pecks on the center key with a force greater than 0.15 N activated the recording and control equipment; pecks on the side keys had no effect. White masking noise was continuously provided via a speaker in the chamber. A Digital Equipment Corporation PDP-8F computer arranged contingencies, presented stimuli, and recorded response latencies in units of 0.01 sec.

### *Procedure*

*The experimental paradigm.* The procedure established over the course of 18 initial training sessions is illustrated in Figure 1. Each session was composed of 200 trials in which the response key was illuminated with a red light for a period of up to 2 sec. A peck during the first second of key illumination produced a 2-sec reinforcement period in which grain was made available. A peck between 1 and 2 sec after stimulus onset turned off both the keylight and the houselight, but it was not reinforced. Each stimulus presentation was preceded by a variable-duration foreperiod (houselight on) and followed by a 2-sec blackout (houselight off). A peck during the foreperiod produced a 4-sec timeout (houselight off), after which the foreperiod began anew.

A short reinforcement duration and fine kernels of grain were used to permit a rather large number of trials per session without subject satiation. The reinforcement of only those responses to occur within 1 sec of key illumination (but the recording of latencies of up to 2 sec) was done in order to maintain

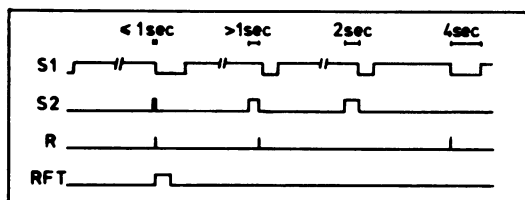


Fig. 1. Illustration of the experimental paradigm. Illumination of the houselight (S1) signalled the beginning of a trial. After the foreperiod had elapsed, the key was illuminated with red light (S2) for at most 2 sec. If a key peck (R) occurred within the first second of key illumination, it was followed by a 2-sec period of grain presentation (RFT), during which the keylight and houselight were off, the latter returning 2 sec later to signal the beginning of a new trial. If a response occurred in the second 1-sec portion of the 2-sec period of key illumination, it was not reinforced: its latency was recorded, the keylight was extinguished, and, at the end of the 2-sec period, the houselight was turned off for 2 sec. If no response occurred during the 2-sec period of key illumination, the houselight went out for 2 sec and no reinforcement was presented. A response emitted during the foreperiod was followed by a 4-sec removal of the houselight (timeout), after which the foreperiod began anew.

fairly short latencies without so constraining this measure as to make the effects of foreperiod duration unobservable. The 2-sec post-stimulus blackout was intended to provide sufficient time for the pigeon to reorient to the key, and thus avoid an artifactual lengthening of response latencies after short foreperiods. Finally, the dependency whereby responses during the foreperiod produced a timeout and restarted the foreperiod, was instituted in order to reduce the frequency of such responses and, thus, of latencies with a spuriously short duration.

**Foreperiod distributions.** Two types of frequency distribution, each with three different mean values, were examined. In the first, foreperiods were distributed arithmetically at 1-sec intervals. The minimum duration was 1 sec, and the maximum duration equalled twice the mean value, minus the 1-sec minimum duration. In this manner, a series of foreperiods was calculated that had means of either 5, 10, or 20 sec. Within a session, this series was repeatedly presented in a different, randomized, sequence. Since 200 trials per session was never an integral multiple of the series length, those trials at the end of the session that constituted a fraction of the length of the series were assigned foreperiods in a quasirandom fashion, without replacement, in such a man-

ner as to maintain the appropriate mean foreperiod duration. For each of the three arithmetic distributions, four different randomized sequences of 200 foreperiods were generated and presented in an irregular order across successive sessions of a condition.

In the constant-probability distributions, the minimum foreperiod duration, as well as the minimum difference ( $T$ ) between durations, was also 1 sec. When the mean foreperiod duration ( $m$ ) is assigned values of 5, 10, and 20 sec, and then substituted in the equation  $p = T/m$ , the probability ( $p$ ) that a stimulus will be presented at each full second of the foreperiod is determined (respectively, 0.2, 0.1, and 0.05). These probabilities can in turn be used to determine the theoretical frequency of a foreperiod of exactly  $k$  sec from among the  $N$  (200) session trials by substitution in the formula below:

$$f(k) = p(1 - p)^k - 1N.$$

Since frequencies must be whole numbers to be of use, the theoretical frequency,  $f(k)$ , was rounded to the nearest whole integer. As  $k$  is increased, the theoretical frequency eventually reaches values of less than one. In this case, each successive 1-sec increment of the foreperiod duration was assigned a frequency of one, until all 200 session trials had been accounted for.

We felt that this method of generating a constant-probability distribution was better suited to our purposes than that of Fleshler and Hoffman (1962), or to a similar method discussed by Catania and Reynolds (1968, Appendix II, p. 381), because, like the arithmetic schedule, it maintained a 1-sec minimum foreperiod duration and stepwidth. Furthermore, the large number of durations in the series (200) prevented an abrupt increase in conditional probability at twice the mean duration, an undesirable characteristic of an otherwise very similar schedule used by Catania and Reynolds (1968) in their third experiment. Finally, the method was also preferable to a purely random determination of foreperiod duration, since it avoided the possibility of extremely long foreperiods and fluctuation of the mean duration over sessions.

**Schedule conditions.** Following reconditioning of the key peck, the eight pigeons were divided into two groups of four. The first group was exposed to arithmetic distributions

Table 1

Summary of mean data from last 10 sessions, each with 200 trials, under mean foreperiod (FP) durations of 5, 10, and 20 sec, for four subjects with arithmetic FP distributions and four with constant-probability distributions. SD is the standard deviation of the 10 mean session latencies. The values for Pigeon F7 in the 5-sec condition are based on only eight sessions because of a problem in data retrieval.

Subject	FP (sec)	No. of Sessions	Latency (sec)	SD	FP Resps.	No- Resp. Trials	Nonre- inforced Resps.
ARITHMETIC							
F1	5	17	0.45	0.01	0.0	0.9	3.1
	10	15	0.53	0.02	0.8	10.3	8.8
	20	17	0.54	0.04	0.6	3.8	7.4
F2	5	15	0.47	0.03	4.1	2.7	7.1
	10	17	0.60	0.03	0.5	6.7	18.1
	20	31	0.64	0.04	0.5	14.8	31.2
F3	5	16	0.63	0.01	0.0	4.2	2.2
	10	17	0.75	0.03	0.1	4.2	6.4
	20	15	0.84	0.02	0.1	4.0	17.2
H2	5	16	0.48	0.04	0.4	2.3	3.0
	10	15	0.62	0.08	1.7	3.5	16.0
	20	18	0.67	0.07	1.0	21.0	19.3
CONSTANT PROBABILITY							
F4	5	15	0.52	0.04	16.1	2.2	5.5
	10	19	0.58	0.05	40.5	9.4	12.1
	20	18	0.63	0.06	19.3	4.0	5.1
F5	5	15	0.58	0.03	1.1	1.3	3.5
	10	18	0.72	0.04	4.3	3.0	12.9
	20	18	0.81	0.04	1.6	4.1	24.2
F6	5	17	0.41	0.04	0.4	2.0	3.9
	10	15	0.51	0.03	0.6	1.4	14.5
	20	17	0.43	0.02	0.9	1.7	2.9
F7	5	15	0.60	0.03	0.3	10.0	3.4
	10	17	0.70	0.03	0.8	5.2	18.6
	20	29	0.74	0.02	0.2	9.8	14.5

of foreperiod duration, whereas the second group was exposed to constant-probability distributions. The reaction-time paradigm, discussed above, was established with a mean foreperiod duration of 10 sec for pigeons of both groups. Then, as shown in Table 1, at least 15 additional sessions were conducted with a 10-sec mean foreperiod duration. The pigeons were then exposed to foreperiod distributions that had mean durations of 5 and 20 sec, respectively, for a minimum of 15 sessions at each value. The order of the pigeons' exposure to these distributions was the same for both groups, and conditions were changed when, over a 10-session period, mean reaction time appeared to be stable.

In general, the data analysis was based on the last 10 sessions of a condition. Occasionally, however, because of a problem in data retrieval, or because of either an unusually

high frequency of responses during the foreperiod or of stimulus presentations to which the pigeon did not respond, a session was excluded from the analysis and subsequently compensated for with an additional session.

## RESULTS

Data from the last 10 sessions of each of the three mean foreperiod conditions are summarized in Table 1 for pigeons of both the arithmetic and constant-probability groups. As shown in the table, a very low frequency of responses during the foreperiod was maintained for all pigeons except F4. As might be expected, foreperiod responses were least frequent during the shortest, 5 sec, foreperiod duration. However, these responses tend to be more frequent at the 10-sec duration (the value to which all subjects were first exposed)

than during the last, 20-sec, condition, an effect that suggests a gradual reduction in the rate of such responses over conditions of the experiment.

Trials in which the pigeons did not respond, or in which a response had a latency of greater than 1 sec and was thus not reinforced, were not systematically related to mean foreperiod duration, although, for several of the pigeons of the arithmetic group, both of these measures appear to increase somewhat with lengthening foreperiod durations.

In Figure 2, mean response latency, or reaction time, is shown as a function of mean foreperiod duration for pigeons of both groups. Except for Pigeon F6, all of the functions can be characterized as increasing and negatively accelerated. Furthermore, there does not appear to be any systematic difference between the two groups: mean reaction time appears to depend on mean foreperiod duration, not on the form of the foreperiod distribution.

Figure 2 further indicates that the latencies obtained in this situation were relatively long when compared with human or animal experiments involving a constrained motor response (e.g., Saslow, 1968; Stebbins and Lanson, 1961).

A more detailed analysis of reaction time as a function of foreperiod duration is provided in Figure 3. Here, latency is plotted as

a function of the duration of the immediately preceding foreperiod. This has been done for each pigeon under each of the three mean foreperiod conditions, under both the arithmetic and the constant-probability foreperiod distributions. To provide an indication of the generally linear trend that seems to characterize these data, straight lines, fitted by the method of least squares,<sup>2</sup> are drawn through the data points. No attempt was made to fit the data of Pigeon F4 under the constant-probability distribution with a mean of 5 sec, since the pattern of latencies appears nonlinear. Also excluded from these calculations were the response latencies at all short foreperiod durations of Pigeon F1, as well as the first mean response latency of F3 in the 5-sec condition. These portions of the functions appear clearly nonlinear, and regression coefficients were calculated from the highest point in each function.

The range of foreperiod durations for which response latencies are plotted for the constant-probability distributions has been set equal to the range of the corresponding arithmetic distribution. In fact, foreperiods of the constant-probability distributions extended to 24 sec in the 5-sec condition, to 37 sec in the 10-sec condition, and to 65 sec in the 20-sec condition. Because of their relative infrequency, determinations of response latency at these long foreperiod durations were more variable, and thus have been excluded from the figure.

With the exception of the data of Pigeon F3, the regression lines all have negative slopes when the distribution of foreperiods is arithmetic, whereas under the constant-probability distribution, all regression lines have a positive slope. In other words, when the conditional probability of stimulus presentation increases with time (the arithmetic distribution), the pigeons tend to respond more quickly at longer foreperiod durations; when the conditional probability is constant, the birds tend to respond somewhat more slowly at longer durations of the foreperiod.

We are at a loss to explain the apparently deviant performance of Pigeon F3: nothing

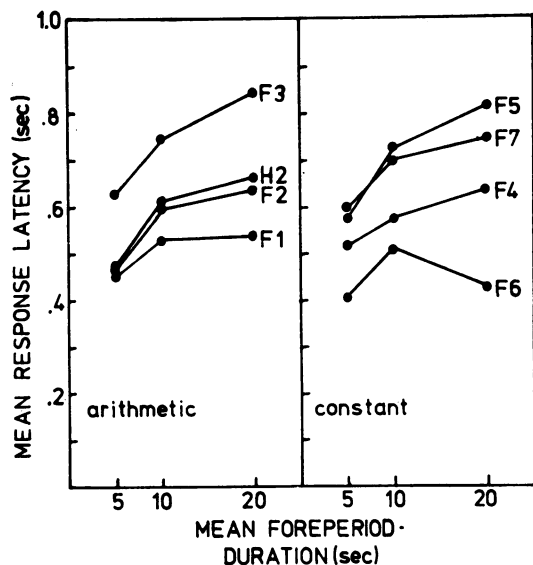


Fig. 2. Response latency as a function of mean foreperiod duration under arithmetic and constant-probability foreperiod distributions. Each point is the arithmetic mean over 10 sessions.

<sup>2</sup>The best-fitting straight lines are shown for illustrative purposes only. In the constant-probability distribution, the number of observations decreases with increasing foreperiod duration, but the fit was done without giving greater weight to shorter foreperiod durations.

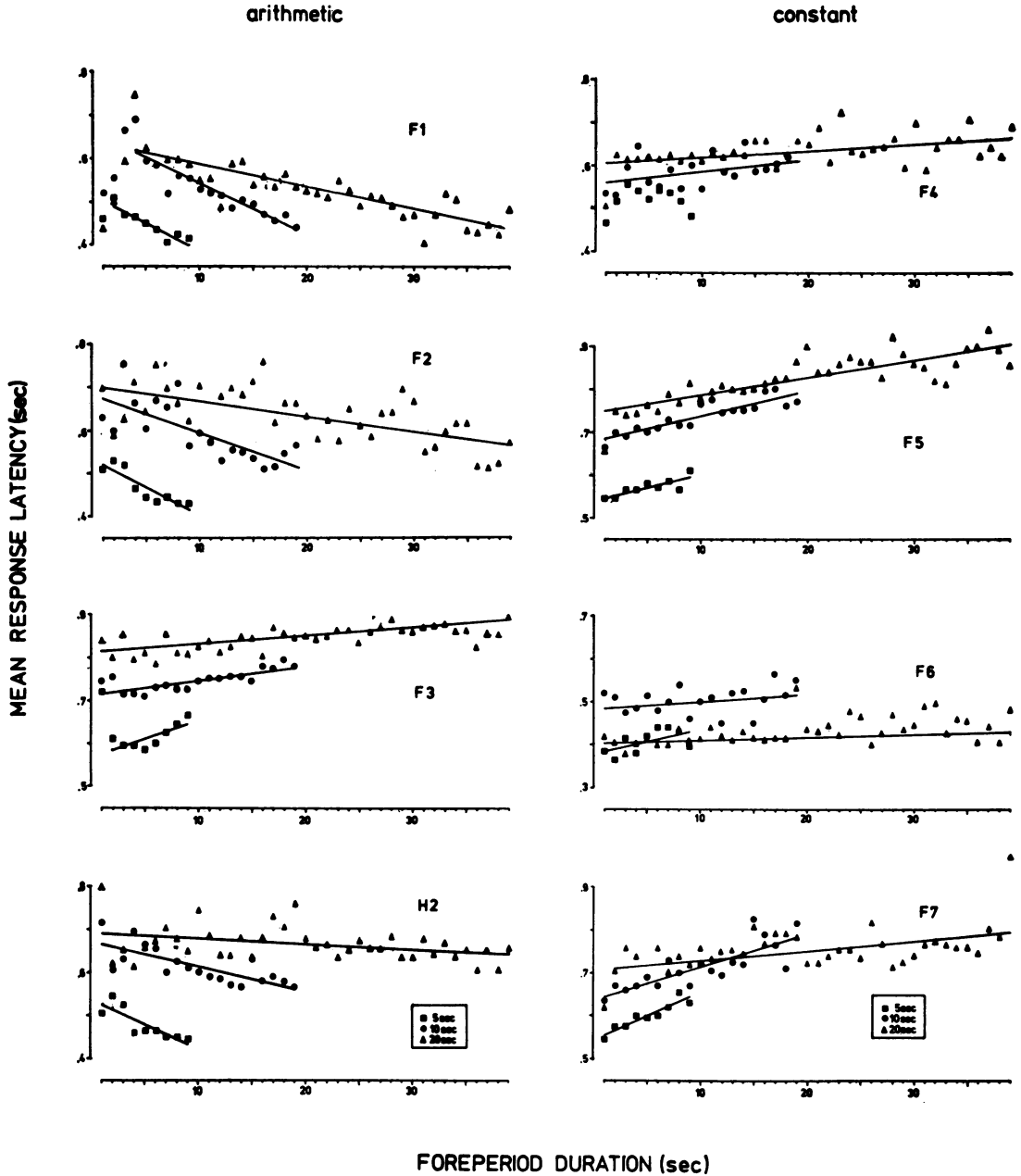


Fig. 3. Mean response latency as a function of the preceding foreperiod. Mean data from 10 sessions are shown for arithmetic and constant-probability distributions, each with three different mean values.

in the bird's behavior during the foreperiod or in its experimental history appeared at all unusual. This pigeon generally had the longest mean latencies of all subjects, as seen in Figure 2, but, in all other respects, the bird's data are virtually the same as those of subjects in the constant-probability group. It simply appears that F3's behavior did not

come under the control of the temporal cues associated with a rising probability of stimulus presentation under the arithmetic foreperiod distribution.

In Figure 3 there is a tendency for the slope of the regression lines to increase with reductions in the mean value of the foreperiod distribution. This effect is most obvious with

the arithmetic distribution, but it can also be discerned in the data obtained under the constant-probability distribution. This finding suggests that the three curves in each panel would be more nearly parallel if, for each of the three conditions, foreperiods were expressed in units relative to the mean of the distribution. All distributions would then have the same range.

The results of this transformation are shown in Figure 4, where each foreperiod duration has been divided by the mean of the foreperiod distribution. A similar transformation has been performed on response latency. To equate differences in the overall latency under the three distributions, each latency has been divided by the mean latency obtained under that distribution.

When plotted in this manner, there is no very great difference in the data obtained under the three mean foreperiod durations. It becomes clear that the form of the functions relating local response latency to foreperiod duration depends not on the *absolute* foreperiod duration, but on the duration of the foreperiod *relative* to that of the other foreperiods in the distribution to which the pigeon is exposed. Again, for three of the four birds exposed to the arithmetic distributions, relative response latency is a generally decreasing function of relative foreperiod duration, whereas, for the constant-probability distribution, the functions are all increasing. There is a suggestion of nonlinearity in the data of Pigeons F1, F2, and H2, all of which were exposed to the arithmetic distribution. Under the 5- and 10-sec mean foreperiod durations, the first point in the functions of all these birds is lower than the second. In the 20-sec condition, this reversal is evidenced by only one bird, H2.

Figure 5 shows the relative frequency of response latencies in class intervals of 0.01 sec. Under both distributions, these curves have a distinctly multimodal character: the first mode generally lies between 0.18 and 0.23 sec, the second between 0.36 and 0.45 sec, and the third between 0.62 and 0.70 sec. This figure clearly demonstrates that the increase in mean response latency that attends longer mean foreperiod durations is not due to a generalized shift of latencies toward longer values. Rather, it is due to an increase in the proportion of latencies that fall in the longer modal

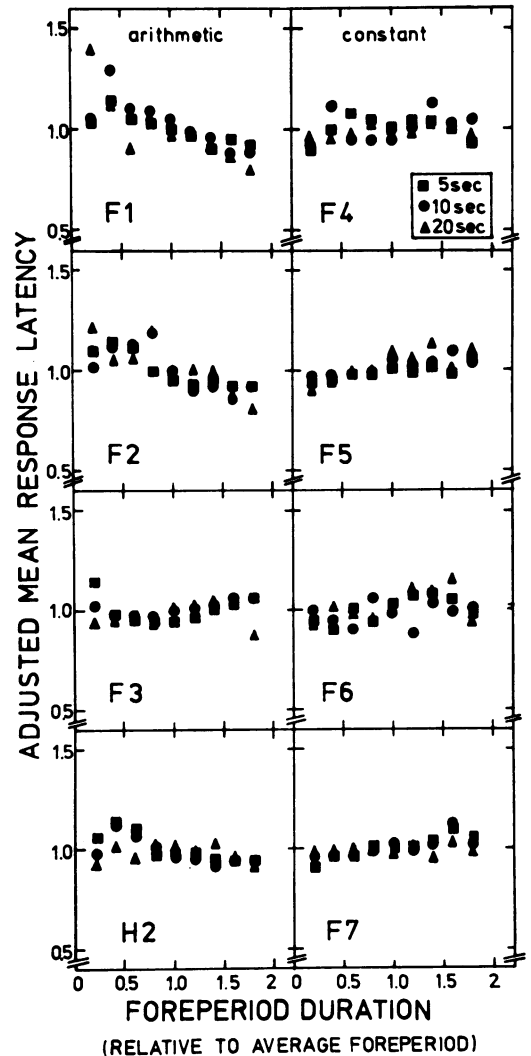


Fig. 4. Adjusted response latency as a function of the relative duration of the immediately preceding foreperiod, under three different mean values of the foreperiod distribution. Relative foreperiod duration is the foreperiod's duration, divided by the mean of the foreperiod distribution. Adjusted response latency is the latency at each relative foreperiod duration, divided by the mean latency across all relative foreperiod durations of a condition. For graphical convenience, only nine different foreperiods are shown for the 10- and 20-sec distributions (seconds 2, 4 . . . 16, 18 of the 10-sec distribution, and seconds 4, 8 . . . 32, 36 of the 20-sec distribution). The relative duration of these foreperiods is the same as that of the nine foreperiods of the 5-sec distribution (1, 2 . . . 8, 9 sec).

classes of an otherwise stationary latency distribution.

It might be speculated that the multimodal latency distribution obtained under a given distribution of foreperiods is due to the addi-

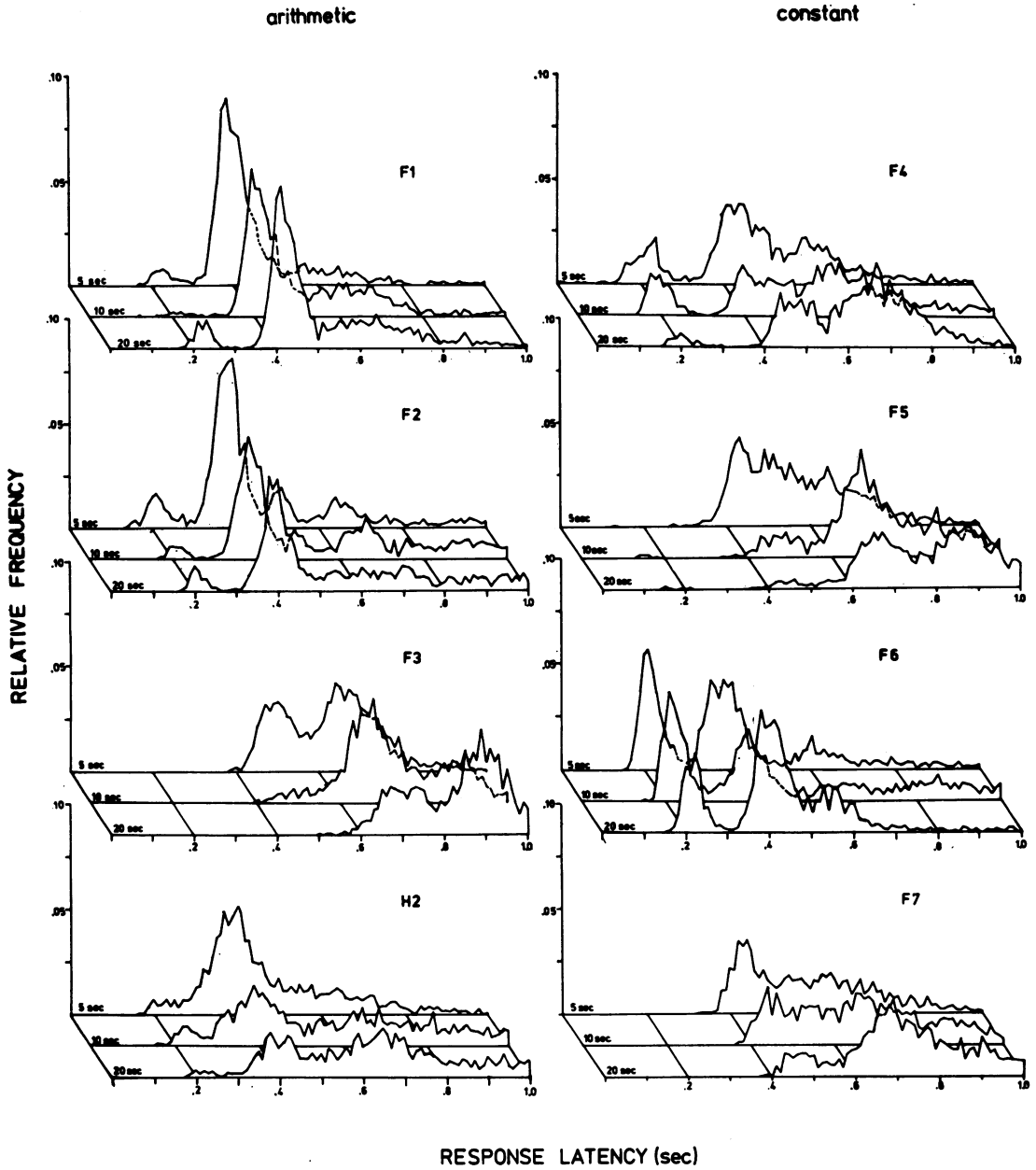


Fig. 5. Relative frequency of response latencies of 1 sec, or less, in class intervals of 0.01 sec for pigeons exposed to either arithmetic or constant-probability distributions.

tion of *unimodal* latency distributions under each of the different foreperiods that make up the distribution. In other words, short foreperiods might be associated with a latency distribution whose mode lies at a low value, and long foreperiods might be associated with a high modal latency. Thus, when long and short foreperiods are mixed, they would pro-

duce a complex multimodal latency distribution of the type shown in Figure 5.

That this is *not* the case, is clearly shown in Figure 6. In this figure, illustrative latency data are presented from two pigeons under the 5-sec condition. Latency distributions are shown separately for each of the foreperiods that make up the distribution. It is evident



that latencies are multimodally distributed under each of the foreperiods that make up the distribution. For Pigeon F2, the foreperiods were distributed arithmetically, and the proportion of latencies at the shortest, 0.20-sec, mode increases as foreperiod duration goes from 1 to 9 sec. Pigeon F6, on the other hand, was exposed to a constant-probability distribution. For this bird, latencies in the shortest modal class decrease, while those in longer classes increase, as the foreperiod duration lengthens.

### DISCUSSION

Research using human subjects and variable foreperiods has shown mean reaction time to be an increasing, negatively accelerated function of mean foreperiod duration, both when foreperiods have a rectangular, or arithmetic, distribution (*e.g.*, Karlin, 1959), and when they have a Bernoulli, or constant-probability, distribution (*e.g.*, Nickerson and Burnham, 1969). The present data from pigeons confirm these findings. They show further that the functions relating mean foreperiod duration to mean reaction time are very much alike under both types of distribution (see Figure 2).

The data from three of the four pigeons that were exposed to an arithmetic distribution of foreperiods also confirm previous

findings with human subjects. Reaction time on a given trial decreased as a function of the length of the immediately preceding foreperiod. With an arithmetic distribution of foreperiods, the longer the time that has elapsed since the beginning of the foreperiod, the more likely it becomes that a stimulus will be presented. Apparently, the reaction time of pigeons, like that of humans, may come under at least the partial control of the conditional probability of stimulus presentation.

Supportive of this conclusion was the finding that when stimuli had a constant probability of presentation, there was evidence of an increase, not a decrease, in response latency as a function of immediate foreperiod length. With the constant-probability distribution of foreperiods, the passage of time in the foreperiod is not correlated with a change in the likelihood of stimulus presentation. Hence, the slower reaction times at longer foreperiods, under this distribution, is an effect that cannot be attributed to discriminative properties of the foreperiod. A very similar effect is to be seen in Granjon *et al.*'s (1973) study of human reaction time under constant-probability foreperiod distributions.

The present experiment further demonstrates that the effect of the foreperiod on the subsequent reaction time is not absolute.

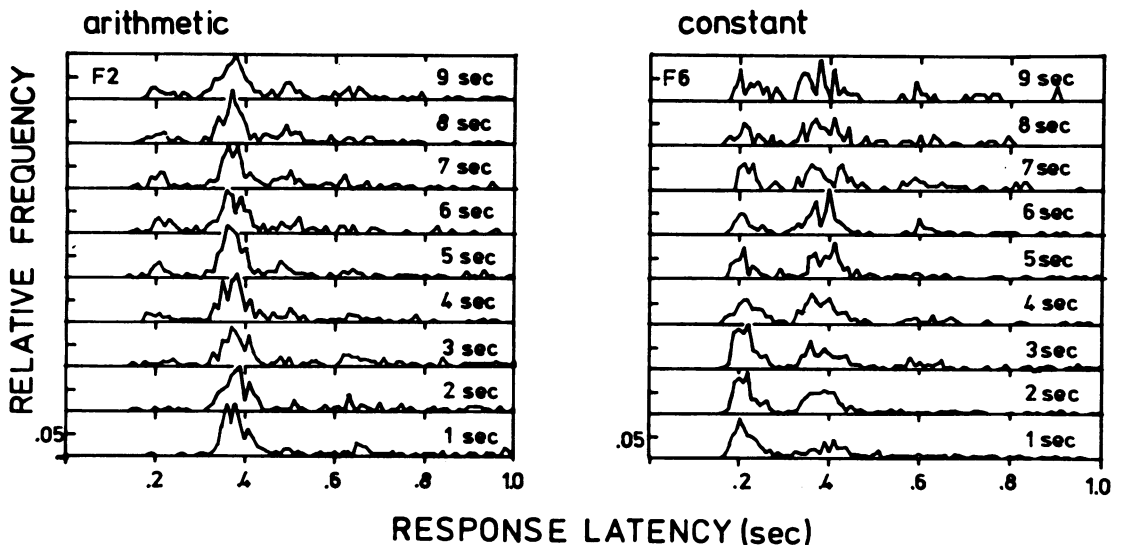


Fig. 6. Relative frequency of response latencies for each foreperiod in the 5-sec condition. Foreperiods were arithmetically distributed for Pigeon F2, whereas they had a constant-probability distribution for Pigeon F6.

The local effects of foreperiod duration appear to depend, instead, on the duration of the foreperiod *relative* to that of the other foreperiods in the series. If overall mean reaction times are equated, and if foreperiod duration is expressed in relative units (Figure 4), then functions relating reaction time to immediate foreperiod duration are very much alike for mean values of either 5, 10, or 20 sec, under both arithmetic and constant-probability distributions.

*Similar effects of interval schedules of reinforcement.* The effect of varied foreperiod duration on response latency is strikingly like that of varied interreinforcement-interval duration on rate of response. Under an interval schedule of reinforcement, a response is reinforced only when a certain amount of time has passed since the onset of a stimulus or since the end of the last reinforcement. This period of time may vary from one interval to the next, as in the VI or variable-interval schedule, or it may remain constant, as in the FI or fixed-interval schedule. In general terms, the simple reaction-time paradigm used in this experiment resembles the VI schedule, the principal differences being that the availability of reinforcement was signalled, and responses before that signal were suppressed.

Noting that response rate is reciprocally related to response latency, an enumeration of several well-established findings regarding FI and VI schedules suggests more than an incidental correspondence with the effects of fixed and variable foreperiod durations.

1. Responding under FI schedules is characterized by a pause after reinforcement, followed, about midway in the interval, by a rapid acceleration to a high steady rate. Response rate in the second of these states is a decreasing, negatively accelerated function of the interreinforcement-interval length (Schneider, 1968).

2. While local response rate is more nearly constant under VI schedules, mean response rate, however, is also a decreasing, negatively accelerated function of the mean interreinforcement-interval duration. Although response rate in the second state of FI schedules is generally higher than mean rate in comparable VI schedules, both show a similar decline with increasing interval duration (*cf.* Schneider, Figure 8).

3. Comparison of arithmetic and constant-

probability (*i.e.*, random-interval) schedules reveals little difference in the effect of variations in the length of the mean interreinforcement interval on rate of response (*cf.* Catania and Reynolds, Figure 25).

4. Local rates of response under arithmetic VI schedules increase monotonically as the time elapses since the last reinforcement. Furthermore, when plotted as a function of relative time since reinforcement (in the manner of Figure 4 in the present study), adjusted rates of response are generally quite similar for arithmetic VI schedules with different mean values (Catania and Reynolds, Figure 3).

5. Unlike the arithmetic schedules, local response rate under constant-probability VI schedules rises rapidly after reinforcement delivery, but then remains quite stable as time passes since reinforcement (Catania and Reynolds, Figures 11 and 12).

All of these effects of FI and VI schedules are at least qualitatively very similar to the effects of fixed and variable foreperiod durations on reaction time. Of particular interest for the present study is Catania and Reynolds' (1968) finding that local response rate under VI schedules is influenced by the conditional probability of reinforcement delivery (or, in their treatment, by the local rate of reinforcement—a measure derived from the conditional probability which attempts to describe a reinforcer's temporal spread of effect). With arithmetic VI schedules, for example, they found that response rate increased as a function of the time that elapsed since the last reinforcement. Our findings were similar: with an arithmetic distribution of foreperiods, response latency decreased as a function of time elapsed in the foreperiod.

With constant-probability VI schedules, Catania and Reynolds reported an initial increase in response rate shortly after reinforcement, but thereafter very stable rates up to durations equal to twice the mean interval length. In our study, we also found that a constant-probability distribution had effects on local reaction times that were clearly different from those of an arithmetic distribution. However, unlike Catania and Reynolds' result, there was a clear tendency for latencies to increase somewhat, rather than remain constant, as a function of the time that had elapsed in the foreperiod.

Many procedural factors might be respon-

sible for this difference in results. One such factor might be that in the constant-probability schedule used in their Experiment 3, the longest interval duration was equal to approximately twice the value of the mean. Thus, the conditional probability of reinforcement rose abruptly to 1.0 at this duration. It may be that this increase in reinforcement likelihood served to maintain constant rates that would have otherwise declined somewhat had intervals in the distribution extended to longer values, as they did in our experiment.

Whatever the reason for this rather small discrepancy in results, it appears that generally, the effects of foreperiod duration on response latency are very like the effects of interval duration on response rate. This conclusion is most strikingly confirmed in the distributions of response latency (Figure 5) obtained under arithmetic and constant-probability distributions with mean durations of 5, 10, and 20 sec. The multimodal character of these distributions, and even the temporal spacing of these modes, is very like that of interresponse time (IRT) distributions under variable-interval schedules of reinforcement (Farmer, 1963; Smith, 1974; Speelman and Gollub, 1974). By comparing our Figure 5 with Farmer's Figure 6, it is apparent that lengthening mean foreperiod durations affect the distribution of response latencies in the same manner that lengthening interval durations affect the IRT distribution in VI schedules. In both cases, lengthening mean durations causes a decrease in the frequency of responses in short modal IRT or latency classes and a corresponding increase at long modal classes.

In short, the pigeon's reaction time appears to be analogous to the IRT of its terminal response in an interval schedule of reinforcement. Visual observation of the pigeons further supported this conclusion: during the foreperiod, all birds made pecking movements in the direction of the key. Usually either the beak did not strike the key or else the force of the peck was insufficient to cause electrical contact.

*Further extensions to human reaction-time research.* Investigators of human reaction time have seldom presented individual reaction-time distributions with a resolution fine enough to determine if the multimodality reported here for the pigeon is also a general characteristic of human performance. In one study that

did so, however, very similar periodicities were evident in the distribution of the reaction time of a verbal response (Venables, 1960). Similarly, Michon (1967), in a finger-tapping tracking task, obtained multimodal distributions of intertap intervals.

The human reaction-time situation seldom permits direct observation of responses during the foreperiod that are of a sub-criterion level. However, when finger tremor has been measured during a manual reaction-time task, it has been found to be rhythmic. Just as the pigeon's key peck often appeared to be a continuation of its bobbing head movements during the foreperiod, so too does the human's finger press occur as a continuation of the downward moving portion of the tremor wave (Lansing, 1956; Travis, 1929).

Human reaction time is often discussed in terms of the subject's *expectancy*, *time-uncertainty*, or *set* (cf. Sanders, 1966). To the degree that the subject's behavior during the foreperiod remains unobserved, such terms denote little more than the observed relation between reaction time and foreperiod duration. The present results and their similarity to effects observed under variable-interval schedules of reinforcement, suggest that future research might make use of procedures, such as Holland's (1957) observing-response technique, which incorporate elements of both the simple reaction-time paradigm and interval schedules of reinforcement. In this way, behavior during the foreperiod could be measured directly.

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